

## CLAIMS

What is claimed is:

1. A multistage catalytic partial oxidation process for recovering elemental sulfur from a H<sub>2</sub>S-containing gas stream, the process comprising:

contacting said H<sub>2</sub>S-containing gas stream with a catalyst that is active for catalyzing the partial oxidation of H<sub>2</sub>S in the presence of oxygen to form S<sup>0</sup> and H<sub>2</sub>O, said catalyst comprising multiple catalytic regions;

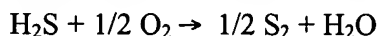
providing the total stoichiometric amount of oxygen required for the catalytic partial oxidation of the H<sub>2</sub>S in said H<sub>2</sub>S-containing gas stream to S<sup>0</sup> and H<sub>2</sub>O in at least two increments, respectively, to at least two of said catalyst regions, such that a product gas mixture is formed comprising S<sup>0</sup> and H<sub>2</sub>O; and

condensing elemental sulfur from said product gas mixture.

2. The process of claim 1 comprising maintaining the temperature of each said catalyst portion above 300°C.

3. The process of claim 1 comprising:

a first stage comprising contacting a first feed gas stream comprising a mixture of H<sub>2</sub>S and an initial incremental of an O<sub>2</sub>-containing gas with a first catalyst portion, said catalyst comprising multiple portions and having activity for catalyzing the partial oxidation of H<sub>2</sub>S to elemental sulfur and water, whereby a first stage product gas mixture is formed, said initial incremental amount of O<sub>2</sub>-containing gas containing less than the stoichiometric amount of O<sub>2</sub> in the reaction



to convert all of the H<sub>2</sub>S in said first feed gas stream, whereby a first stage product gas stream comprising elemental sulfur, steam and unreacted hydrogen sulfide is obtained;

a second stage comprising contacting said first stage product gas stream with a second catalyst portion following said first catalyst portion;

combining a second incremental amount of O<sub>2</sub>-containing gas with said first stage product gas stream, said second incremental amount of O<sub>2</sub>-containing gas containing less than the stoichiometric amount of O<sub>2</sub> in said reaction to convert all of the unreacted H<sub>2</sub>S in said first stage product gas stream to S<sup>0</sup> and H<sub>2</sub>O, whereby a second stage product gas stream comprising S<sup>0</sup>, H<sub>2</sub>O and unreacted H<sub>2</sub>S is obtained; and

optionally, a third stage comprising combining a third incremental amount of O<sub>2</sub>-containing gas with said second stage product gas stream, said third incremental amount of O<sub>2</sub>-containing gas containing less than the stoichiometric amount of O<sub>2</sub> in said reaction to convert all of the unreacted H<sub>2</sub>S in said second stage product gas stream to S<sup>0</sup> and H<sub>2</sub>O, whereby a third stage product gas stream comprising S<sup>0</sup>, H<sub>2</sub>O and unreacted H<sub>2</sub>S is obtained.

4. The process of claim 3 comprising regulating the concentration of O<sub>2</sub> in said initial feed gas mixture and the amount of O<sub>2</sub> provided in said second incremental amount of O<sub>2</sub>-containing gas such that at least 85% of the H<sub>2</sub>S component of the initial feed gas mixture is converted to S<sup>0</sup> and H<sub>2</sub>O by said first and second stages together.

5. The process of claim 3 including said third stage and comprising:  
regulating the concentration of O<sub>2</sub> in said initial feed gas mixture,  
regulating the amount of O<sub>2</sub> provided in said second incremental amount of O<sub>2</sub>-containing gas, and

regulating the amount of O<sub>2</sub> provided in said third incremental amount of O<sub>2</sub>-containing gas, such that at least 90% of the H<sub>2</sub>S component of the initial feed gas mixture is converted to S<sup>0</sup> and H<sub>2</sub>O by said first, second and third stages together.

6. The process of claim 3 comprising maintaining a O<sub>2</sub>:H<sub>2</sub>S molar ratio of less than 0.5 in said initial feed gas stream when contacting said initial catalyst portion.

7. The process of claim 6 comprising establishing a O<sub>2</sub>:H<sub>2</sub>S molar ratio in the range of 0.30 to 0.43 at the beginning of each of said first, second and third stages.

8. The process of claim 3 comprising:  
passing said second or third stage product gas mixture into a cooling zone and cooling said gas mixture sufficiently to form liquid sulfur and a desulfurized effluent gas stream.

9. The process of claim 8 wherein said cooling comprises:  
cooling said gas mixture to a temperature above the dewpoint of sulfur, to provide a partially cooled product stream;

passing said partially cooled product stream into a sulfur condenser and further cooling said partially cooled product stream to the dewpoint temperature of gaseous elemental sulfur, or lower, but above the melting point of solid sulfur, such that the liquid phase of said sulfur product is favored; and

withdrawing liquid sulfur from said sulfur condenser.

10. The process of claim 1 comprising maintaining the temperature of said catalyst in the range of 700-1,500°C.

11. The process of claim 10 comprising maintaining the temperature of said catalyst between about 850°C - 1,300°C.

12. The process of claim 1 comprising preheating said H<sub>2</sub>S-containing gas stream to about 200°C before contacting said first catalyst portion.

13. The process of claim 1 comprising maintaining a catalyst contact time of no more than about 200 milliseconds.

14. The process of claim 1 comprising operating said process at a space velocity of at least about 20,000 h<sup>-1</sup>.

15. The process of claim 1 comprising operating said reactor at superatmospheric pressure.

16. The process of claim 1 wherein said catalyst comprises a refractory support chosen from the group consisting of one or more oxides of Al, Zr, Mg, Ce, Si, La, Sm and Yb.

17. The process of claim 1 wherein said catalyst comprises at least one metal chosen from the group consisting of Pt, Rh, Ru, Ir, Ni, Pd, Fe, Cr, Co, Re, Rb, V, Bi, Sn and Sb.

18. The process of claim 17 wherein said catalyst comprises Pt, Rh or a mixture thereof.

19. The process of claim 17 wherein said catalyst comprises V, Bi, Sn or Sb.

20. The process of claim 17 wherein said catalyst further comprises at least one lanthanide element chosen from the group consisting of La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu.
21. The process of claim 17 wherein said catalyst further comprises at least one alkaline element chosen from the group consisting of Mg, Ca and Ba.
22. The process of claim 21 wherein at least one said lanthanide element is Sm, Yb or Pr.
23. The process of claim 21 wherein said catalyst comprises platinum and samarium oxide.
24. The process of claim 21 wherein said catalyst comprises platinum and magnesium oxide.
25. The process of claim 21 wherein said catalyst comprises rhodium and samarium oxide.
26. The process of claim 21 wherein said catalyst comprises rhodium and magnesium oxide.
27. The process of claim 21 wherein said catalyst comprises a platinum-rhodium alloy on a lanthanide oxide coated refractory support.
28. The process of claim 27 wherein said catalyst comprises a samarium oxide coated refractory support.
29. The process of claim 21 wherein said catalyst comprises a platinum-rhodium alloy on a alkaline oxide coated refractory support.
30. The process of claim 29 wherein said catalyst comprises a magnesium oxide coated refractory support.
31. The process of claim 17 wherein said catalyst comprises at least one carbided metal.
32. The process of claim 31 wherein said carbided metal comprises platinum and rhodium.

33. The process of claim 1 wherein said catalyst comprises at least one structure chosen from the group consisting of gauzes, monoliths and a plurality of divided units.
34. The process of claim 33 wherein said divided units comprise particles, granules, beads, pills, pellets, cylinders, trilobes, extrudates or spheres.
35. The method of claim 34 wherein each said divided unit is less than 25 millimeters in its longest dimension.
36. The method of claim 35 wherein each said divided unit is less than 10 millimeters in its longest dimension.
37. A sulfur recovery system comprising:  
a reactor having multiple reaction zones in serial flow arrangement, each said reaction zone comprising a catalyst having activity for catalyzing the partial oxidation of  $\text{H}_2\text{S}$  to elemental sulfur and water in the presence of  $\text{O}_2$ , and each said reaction zone having an inlet for introducing an  $\text{O}_2$ -containing gas stream into a respective reaction zone; and  
a cooling zone for receiving and cooling reacted gases from the last of said multiple reaction zones, and comprising a sulfur condenser having a liquid sulfur outlet and a desulfurized gas outlet.
38. The system of claim 37 further comprising at least one tail gas treatment unit.
39. The system of claim 38 further comprising a heater disposed between said desulfurized gas outlet and said tail gas treatment unit.
40. The system of claim 37 wherein said reactor is capable of withstanding temperatures of at least about  $1,300^\circ\text{C}$ .
41. The system of claim 37 wherein said cooling zone comprises a plurality of thermally conductive tubes.
42. The system of claim 41 wherein said cooling zone further comprises at least one thermal insulator between said reaction zone and said thermally conductive tubes.

43. The system of claim 42 wherein said at least one thermal insulator comprises at least one refractory ferrule, each said ferrule attached to a thermally conductive tube.
44. The system of claim 37 wherein said cooling zone comprises a heat exchanger.